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# What determines the impact of context on sequential action?

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In the current study we build on earlier observations that memory-based sequential action is better in the original learning context than in other contexts. We examined whether changes in the perceptual context have differential impact across distinct processing phases (preparation versus execution of a motor chunk) within an ongoing movement sequence. Participants were trained on two discrete keying sequences, each of which was systematically presented in its own unique color during a practice session with either limited or extended practice. In a subsequent test session, sequences were performed with the same, with reversed, and with completely novel sequence-specific colors. The results confirm context-dependence in sequential action, the relevance of practice for its development, and its selective expression for the preparation but not the execution of highly practiced motor chunks. As such, the current study provides novel insights into the determinants of context-dependent sequential action. We finish by outlining the overall status of context-dependence in sequential motor behavior, and specify a general working model.



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## 1. Introduction

The ability to acquire and perform action sequences is essential for everyday behavior, as most complex actions that people perform (e.g., lacing a shoe or playing the piano) consist of a series of simple movements that are executed in a specific order. Research has shown that such sequential action can become context-dependent – that is, performance has been found to be better in the original acquisition environment, as compared to different environments (e.g., Abrahamse & Verwey, 2008; Anderson, Wright, & Immink, 1998; Ruitenberg, Abrahamse, De Kleine, & Verwey, 2012; Ruitenberg, De Kleine, Van der Lubbe, Verwey, & Abrahamse, 2012; Shea & Wright, 1995; Wright & Shea, 1991). Context here refers to those perceptual features of the task setting that are not formally required for successful task performance, yet that may influence performance with practice based on contingencies with task-relevant information. Indeed, context-dependent learning and related concepts such as procedural reinstatement or specificity of learning (Healy, Wohldmann, Parker, & Bourne, 2005) are typically related to the notion that context-features become associated with the task during acquisition and subsequently enhance performance by acting as a cue for memory retrieval processes (e.g., Healy et al., 2005; Wright & Shea, 1991).

In recent studies (Ruitenberg, Abrahamse, et al., 2012; Ruitenberg, De Kleine, et al., 2012) we have focused specifically on context-effects in discrete sequential action – the execution of short and fixed series of simple movements (i.e., key presses) at high pace. Such effects are both surprising and important because they show the ongoing relevance of (perceptual) context even in predominantly motoric tasks. In one of our earlier studies (Ruitenberg, Abrahamse, et al., 2012) the overall notion of impaired memory-based sequencing performance upon contextual changes was confirmed, but more specific predictions on the distinct sensitivity to context-effects of preparation and execution phases (see below) in such sequential action were not supported. Here we reexamine this issue using an improved experimental design.

### 1.1. Discrete sequential action

A task that is well-suited for studying the cognitive processes underlying sequential action is the discrete sequence production (DSP) task (Abrahamse, Ruitenberg, De Kleine, & Verwey, 2013; Verwey, 1999; Verwey, Abrahamse, & De Kleine, 2010). This task typically involves series of two to seven stimuli that are presented in a fixed order. Each single stimulus remains on the screen until participants respond to it by means of a spatially compatible key press, after which the next stimulus of the series immediately appears (response-to-stimulus interval of 0 ms). Two fixed series of stimuli (and corresponding responses) are practiced extensively in random order so that a discrete sequence skill develops for each sequence. Due to the relatively simple responses in the form of key presses, the motor control component in this task is minimized (e.g., little need for joint angle or force control) such that cognitive control mechanisms involved in sequencing performance can be optimally examined.

Based on work with this task a Dual Processor Model (DPM) of discrete sequence production has been developed (Abrahamse et al., 2013; Verwey, 2001). According to the DPM, sequencing performance involves sequence retrieval and motor buffer loading by a cognitive processor (i.e., preparation processes), followed by the fast execution of the motor buffer content by a dedicated motor processor (i.e., execution processes). The precise content that is loaded into the motor buffer changes over practice. Initially, the cognitive processor loads each individual element – that is, key press – by translating each stimulus into the appropriate response, which is then directly executed by the motor processor. With practice, *motor chunks* develop: representations of a series of successive responses that can be retrieved and loaded as if they were a single response. The cognitive processor can thus select and load such a chunk into the motor buffer as a whole, after which the motor processor executes all elements within the chunk. This means that the response time on the first key press of a motor chunk reflects selection, retrieval and execution (i.e., *preparation phase*), while response times on later key presses primarily reflect execution processes (i.e., *execution phase*) because motor chunk selection and retrieval had already occurred.

Importantly, if total sequence length exceeds the limited capacity of a single motor chunk (about four key presses; e.g., Bo & Seidler, 2009), then a sequence will be segmented into multiple successive